Abuse characterization and simulation of battery cells and cell arrangements

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16th LS-DYNA Forum 2022

Testing and Identification

Material

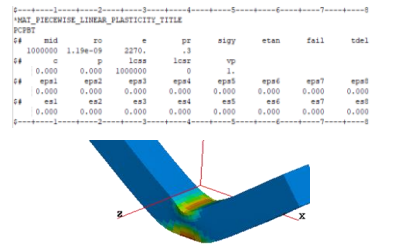
IMPETUS

Testing

VALIMAT

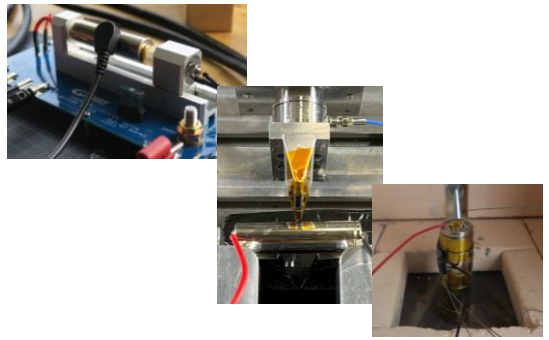
Identification

MATERIAL cards

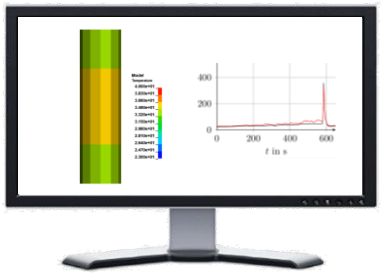


Material model

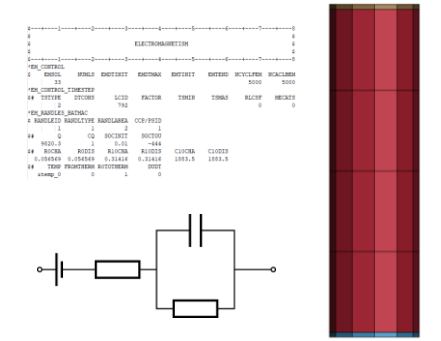
Battery Cell



Testing

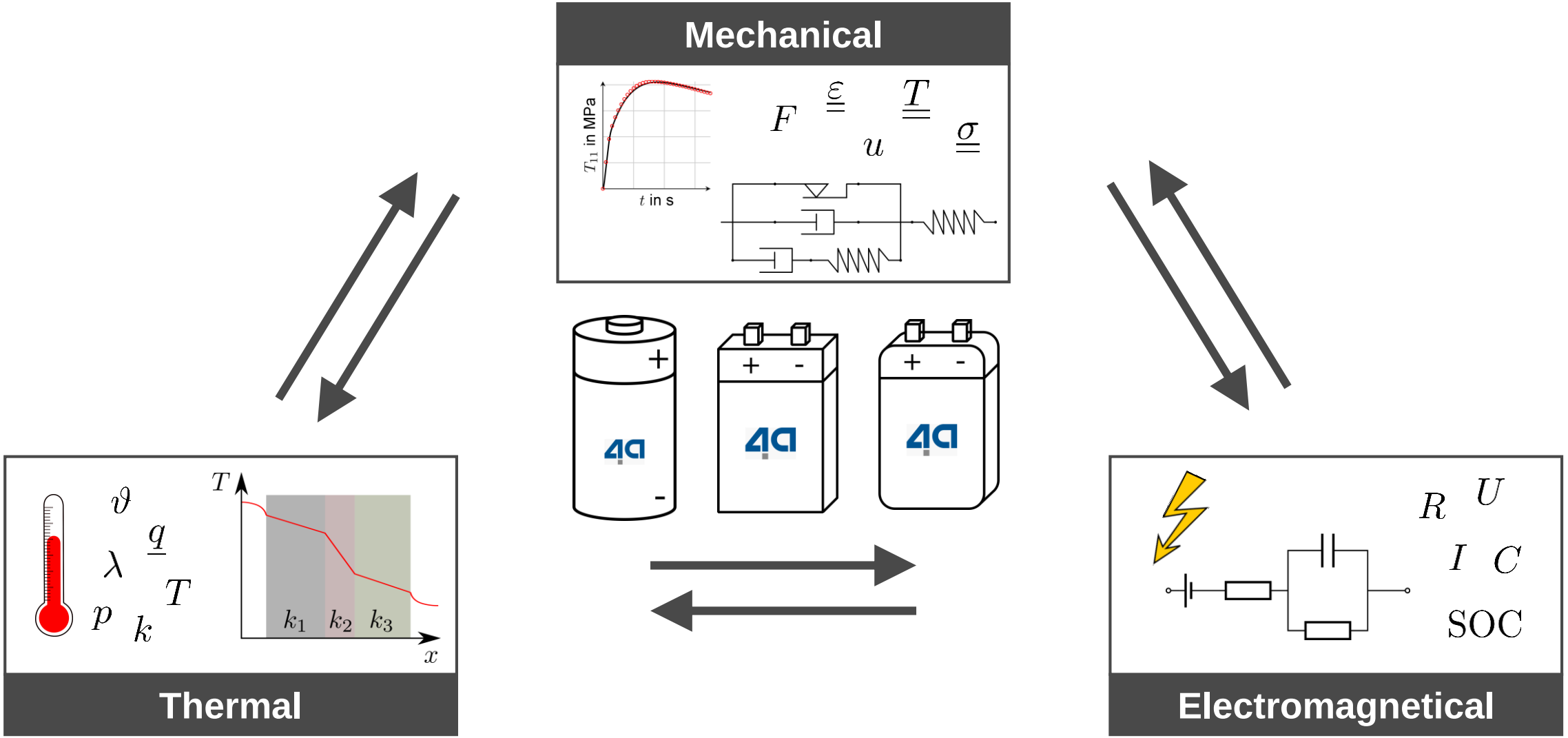


Identification



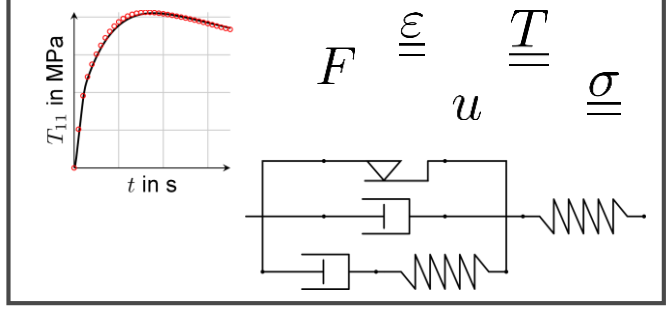
FE Model

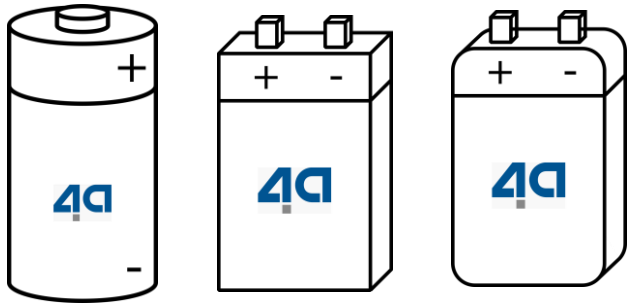
Multiphysics of battery cells



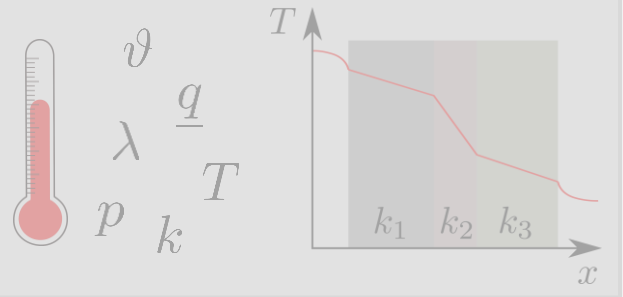
Multiphysics of battery cells

Mechanical

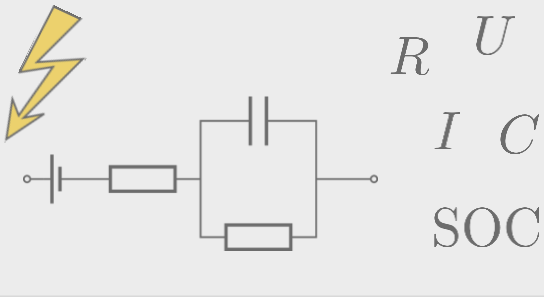




Thermal

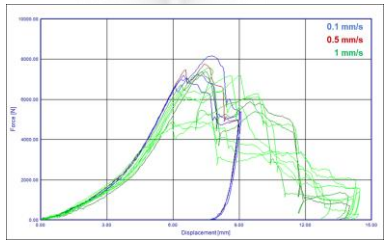


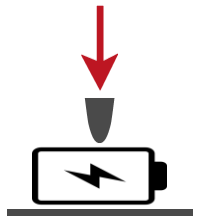
Electromagnetical

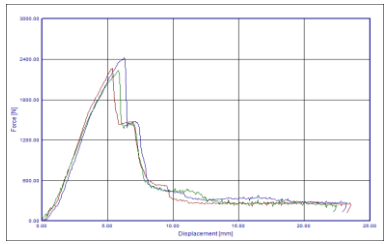


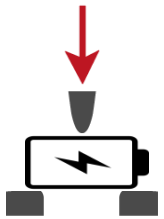
Creation of the mechanical simulation model with VALIMAT® & LS-DYNA

Testing

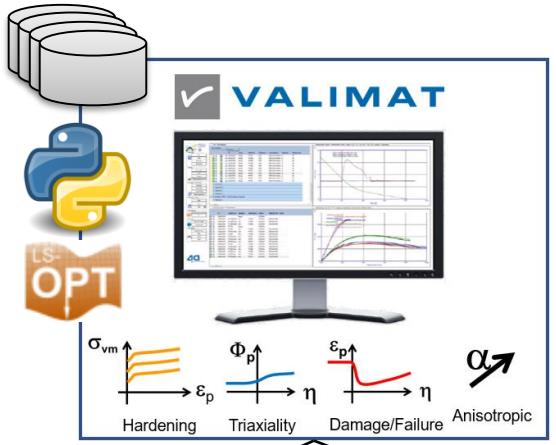




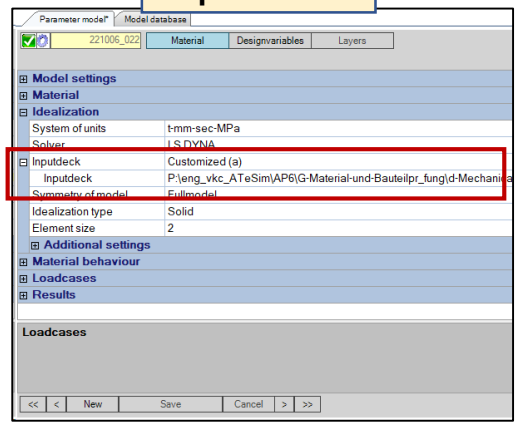




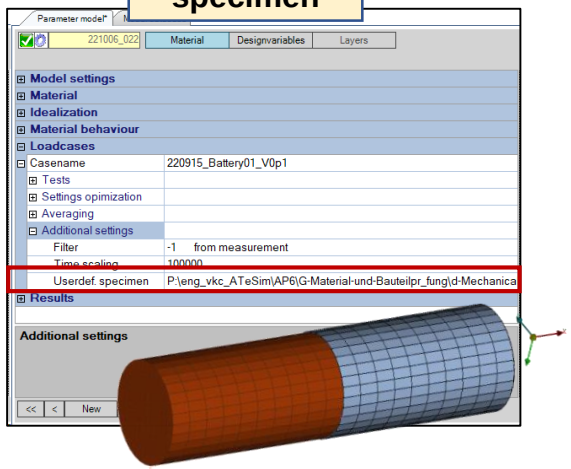
Optimization of material parameters for single battery cell



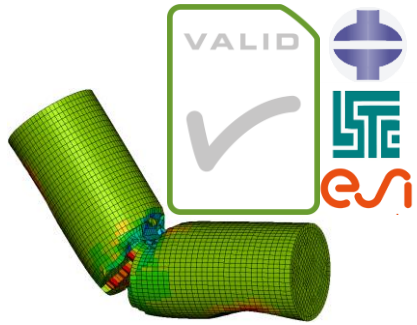
User defined input decks

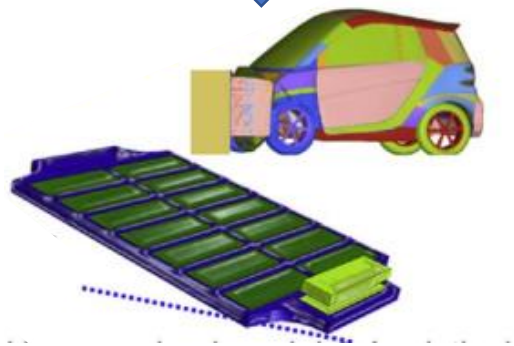


User defined specimen



Validation and Implementation to bigger models



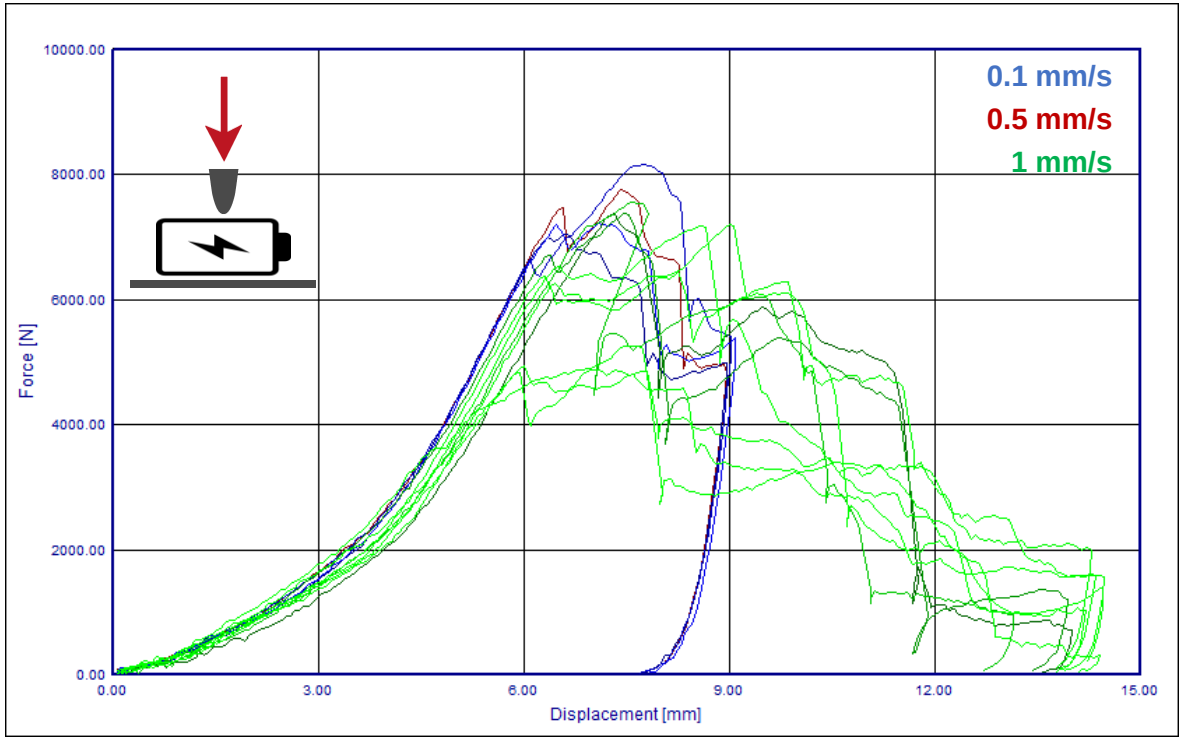


Source: Zhu et. al; „A review of safety-focused mechanical modeling of Commercial lithium-ion batteries“, Journal of Power Sources 378 (2018) 153-168

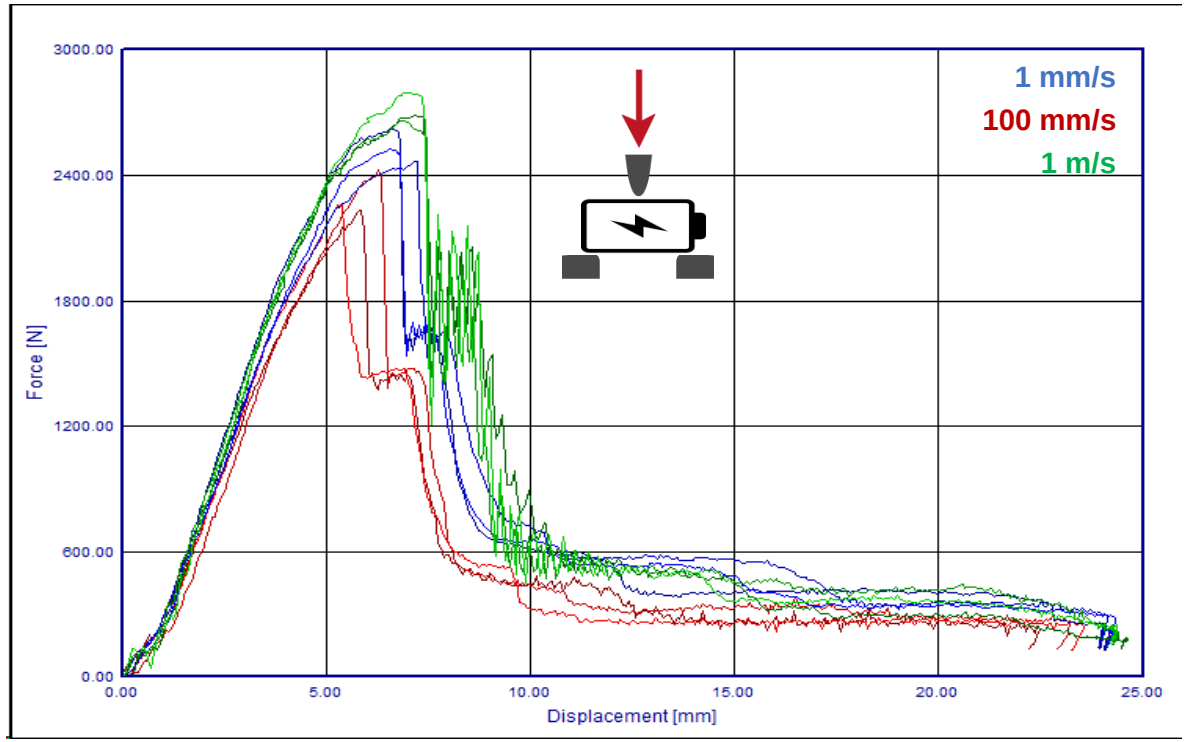
Mechanical Test results overview - 18650 battery cell

LINOVIS
high performance modular testing

Plane strain indentation



3 point bending



- Remark: Different test setup used for the 1mm/s (max penetration displacement differs).

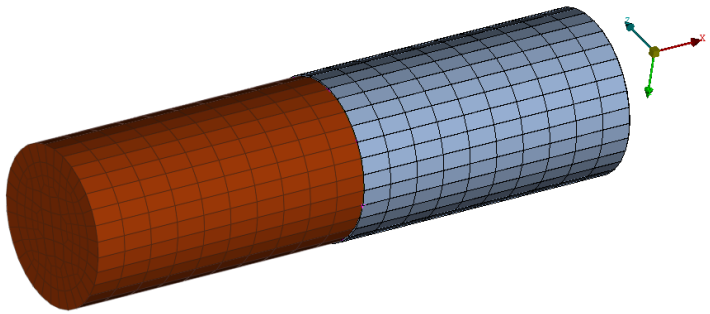
FE model overview – 18650 battery cell

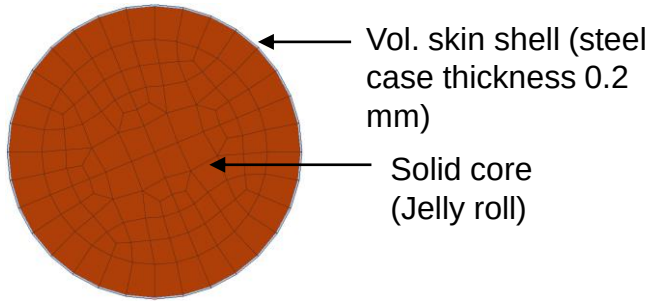
Geometry

- Cylindrical battery cell 18650
- 65mm x 18mm x 18mm

Battery cell mesh

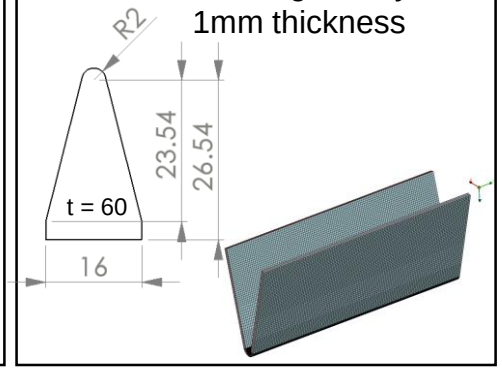
- Mesh:
  - Jelly roll: Solid, ELFORM 1, approx. size 2 mm, number of elements 2400
  - Steel case: Vol. shell skin, ELFORM 16, thickness 0.2 mm, number of elements 880





Intruder mesh

- Intruder:
  - Fin 2mm radius
  - Shell rigid body, 1mm thickness



Material models

- Material models:
  - Jelly roll: *MAT_CRUSHABLE_FOAM (MAT063)
  - Steel casing: *MAT_PIECEWISE_LINEAR_PLASTICITY_TITLE (MAT024)

Contacts

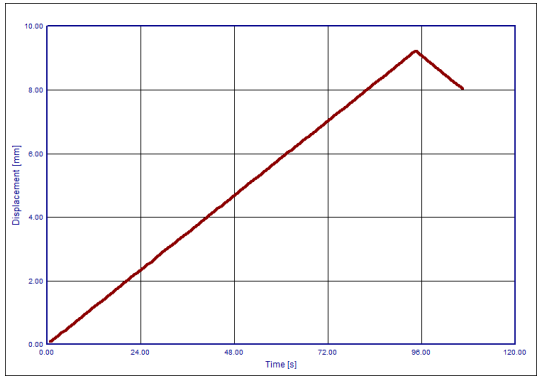
- Contact definition: (*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE with SOFT=1):
  - Fin - Steel_case
  - Fin - Jelly_roll
  - Steel_case – Jelly_roll

Solver

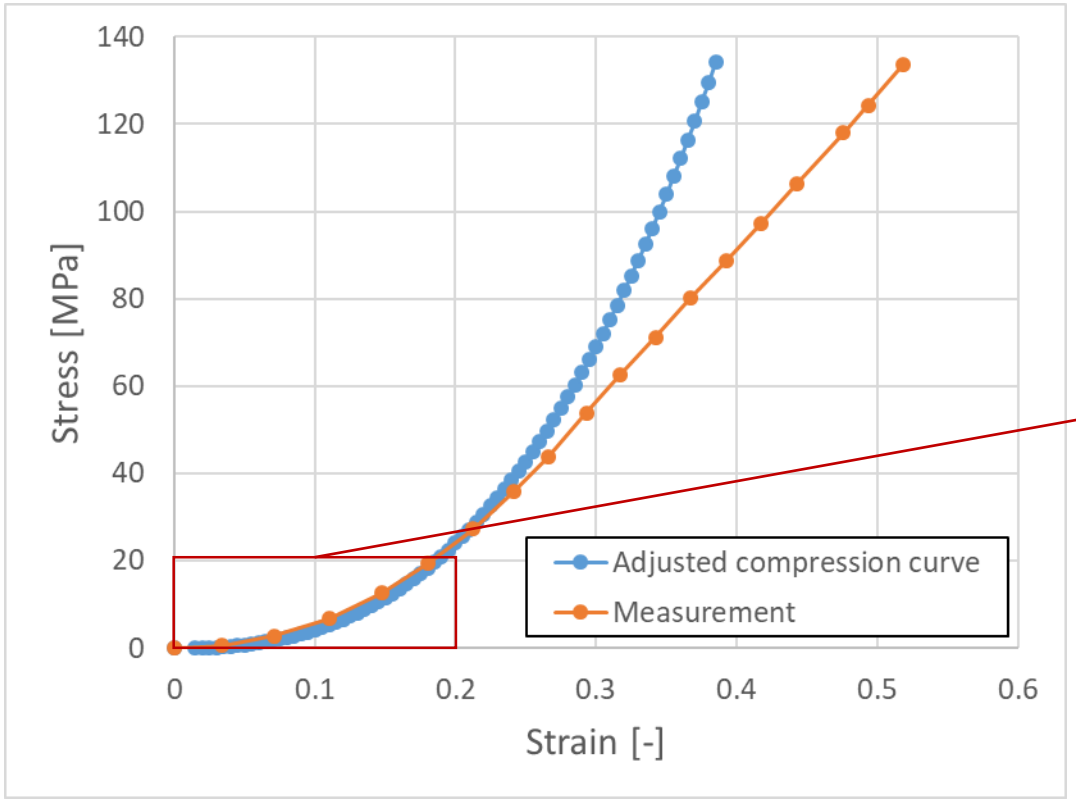
- LS-DYNA R13.1.1

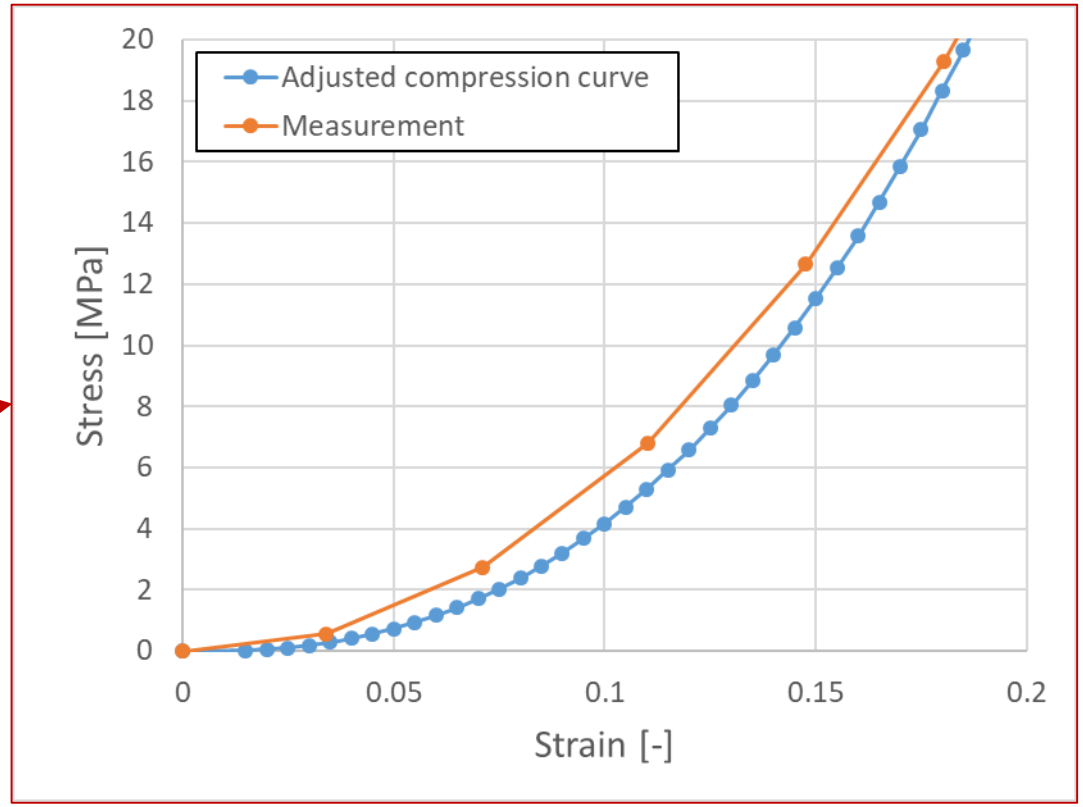
Load

- *BOUNDARY_PRESCRIBED_MOTION_RIGID_ID:
  - Displacement curve from plane crush battery test (VALIMAT® DB)



Crushable foam MAT063 compression curve optimization





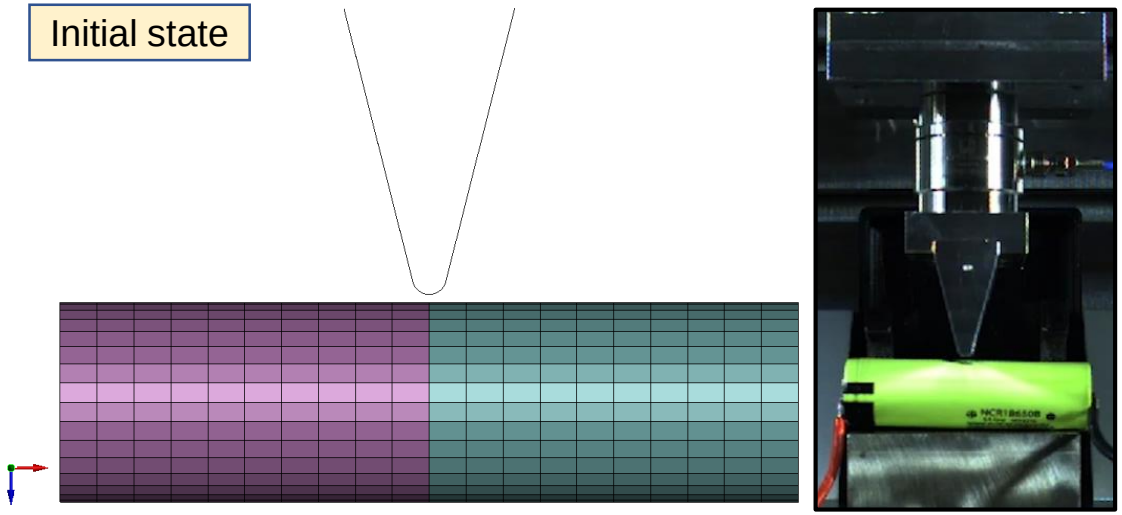
Initial compression curve for start of optimization taken from literature (orange curve).
Optimized compression curve identified via reverse engineering (blue curve).

Source: Sahraei et. al; „Modelling and short circuit detection of 18650 Li-ion cells under mechanical abuse conditions“, Journal of Power Sources 220 (2012) 360-372

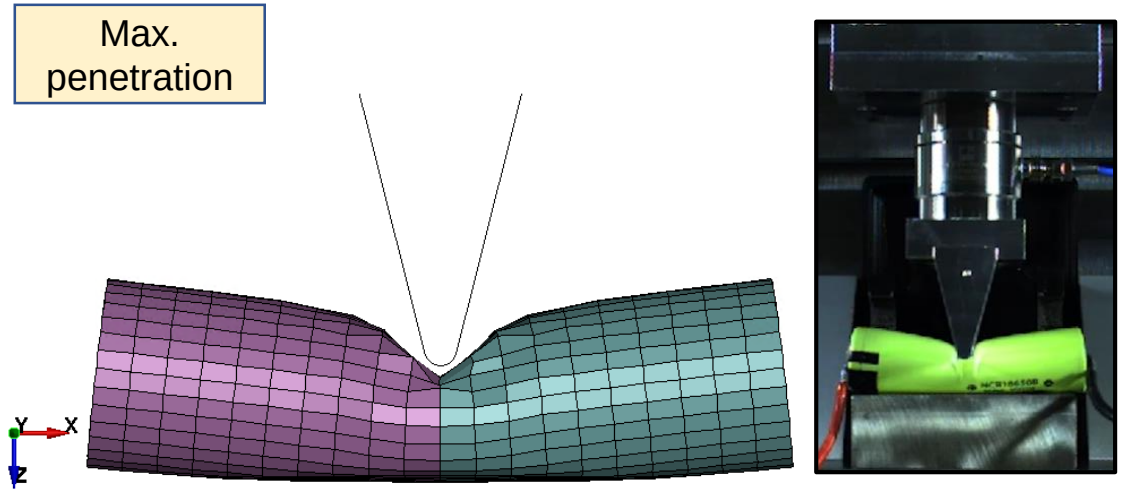
Analysis results - 18650 battery cell

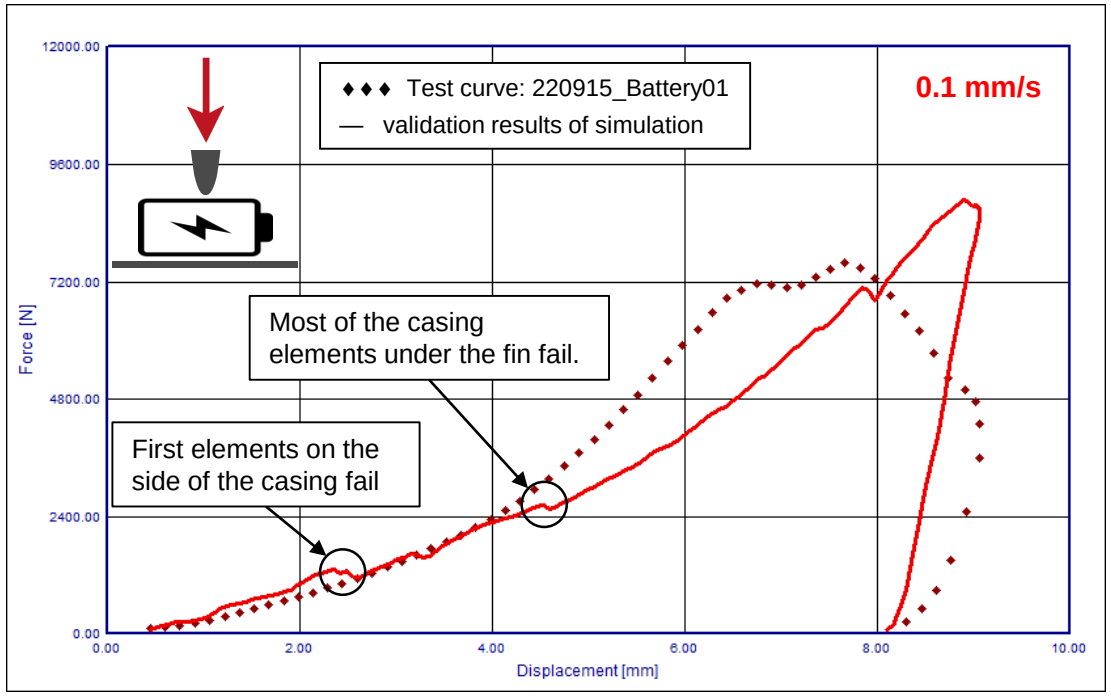
Plane-crush, default MAT024 & MAT063 (based on literature values)

Initial state



Max. penetration



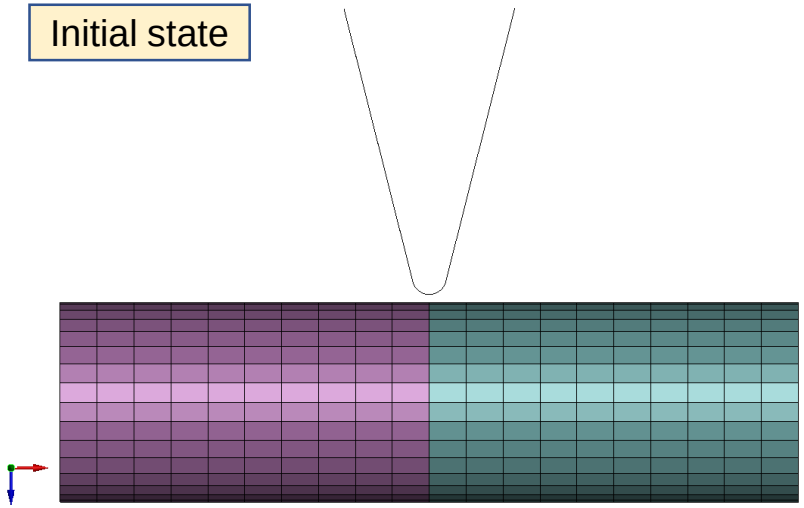


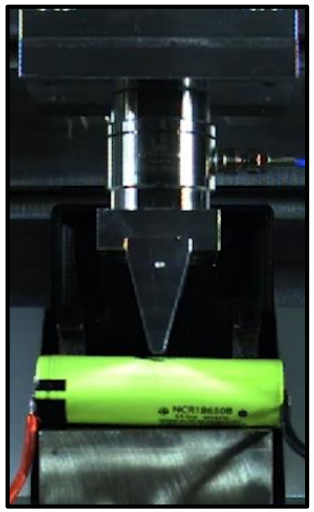
- Plane-crush mechanical simulation model shows similar stiffness up to 4 mm displacement. After this point most of the fin contact switches from the battery casing to the jelly roll of the battery.
- Densification is underestimated → adjustment of compression curve required

Analysis results - 18650 battery cell

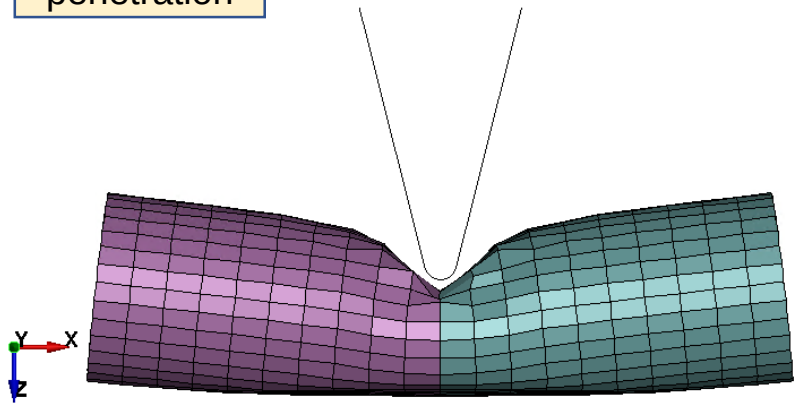
Plane-crush, adjusted MAT024 & MAT063+MAT_ADD_EROSION

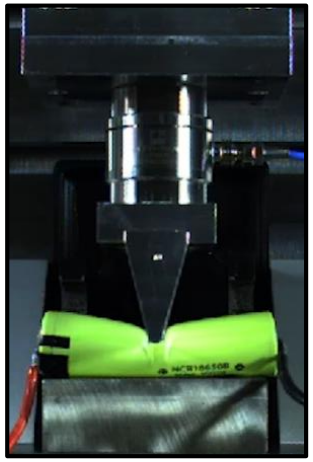
Initial state

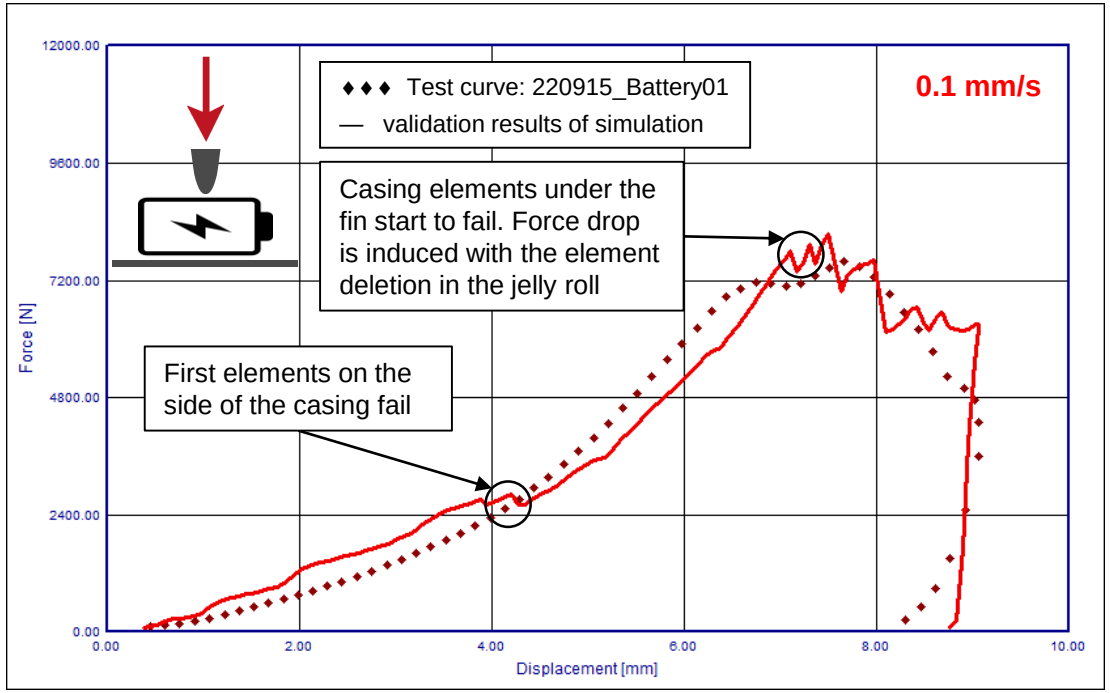




Max. penetration







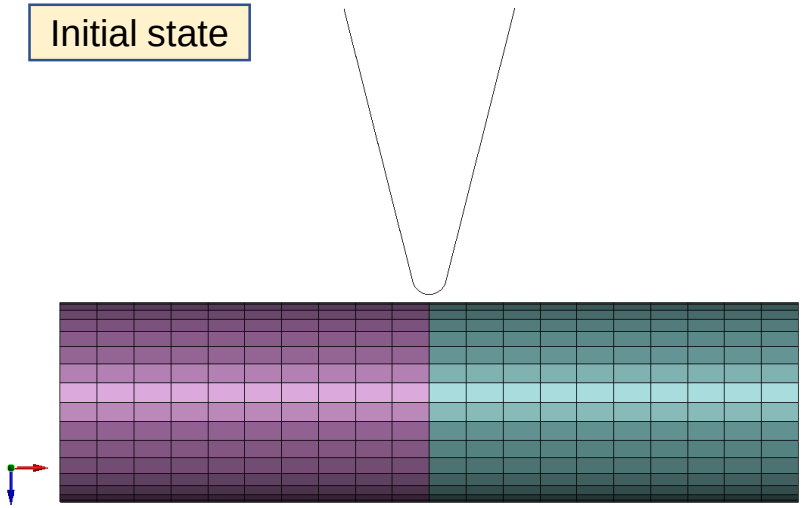
- Element deletion in the MAT063 allowed simulation model to follow the measurement force-displacement curve more accurately.
- MAT_ADD_EROSION (MXPRES maximum pressure at failure criterion)

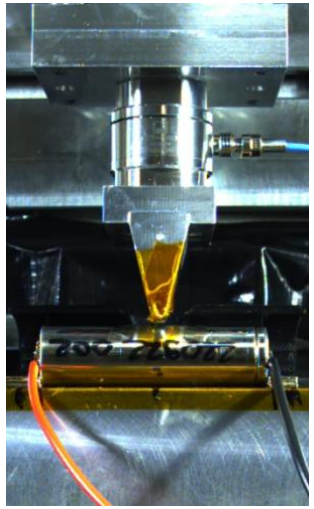
```
*MAT_ADD_EROSION_TITLE
22100502_vkc_custom_18650-JellyRoll_T23_MAT063_MPa
$      MID      EXCL     MXPRES      MNEPS     EFFEPS     VOLEPS     NUMFIP        NCS
   2000000                    50                            0.7         1.
$   MNPRES      SIGP1      SIGVM      MXEPS      EPSSH     SIGTH    IMPULSE     FAILTM
                                                 0.55
```

Analysis results - 18650 battery cell

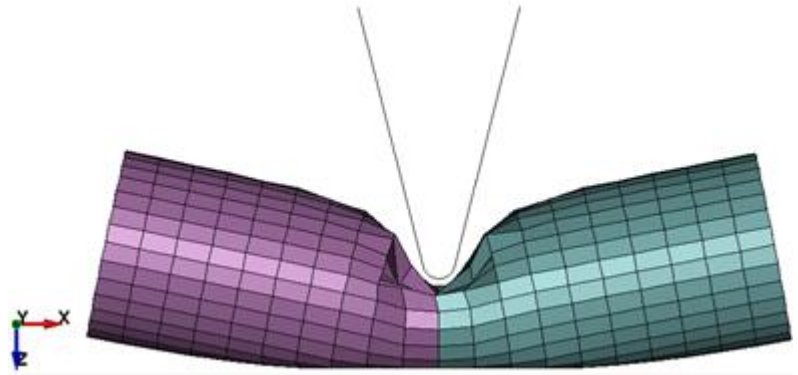
Plane-crush, adjusted MAT024 & MAT063+MAT_ADD_EROSION

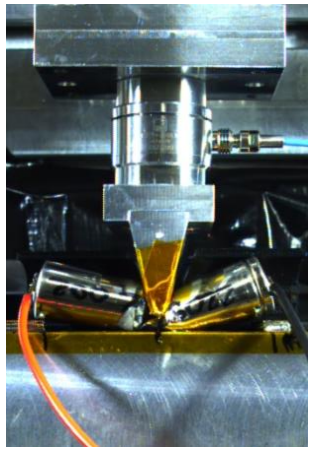
Initial state

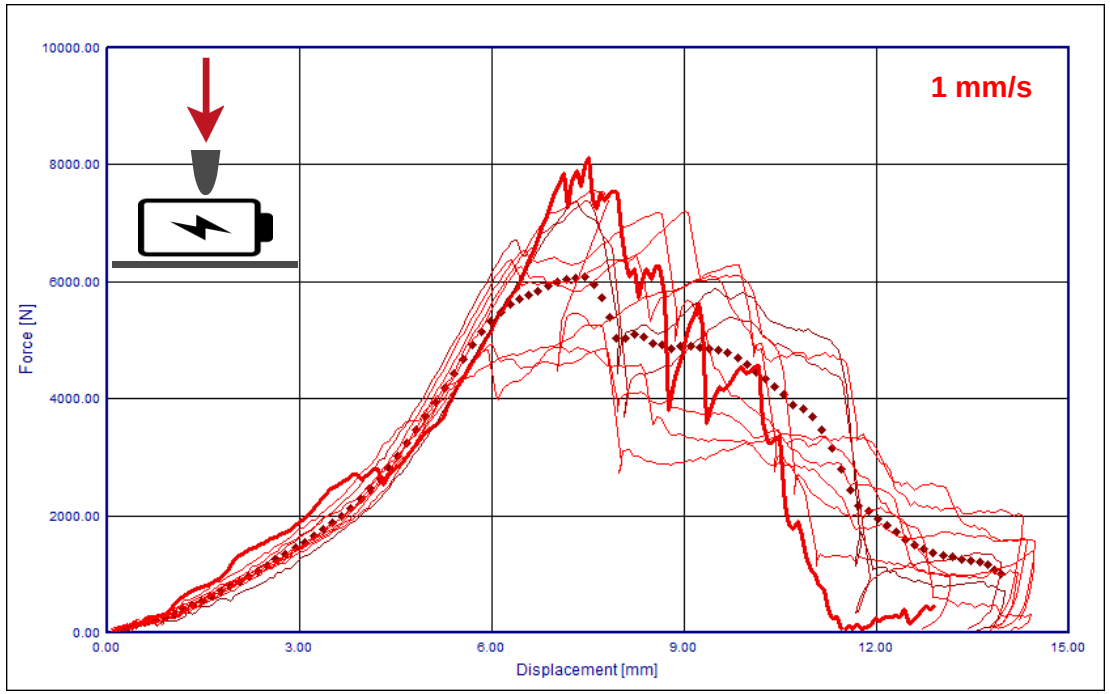




Max. penetration







♦♦♦ Mean value curves testing

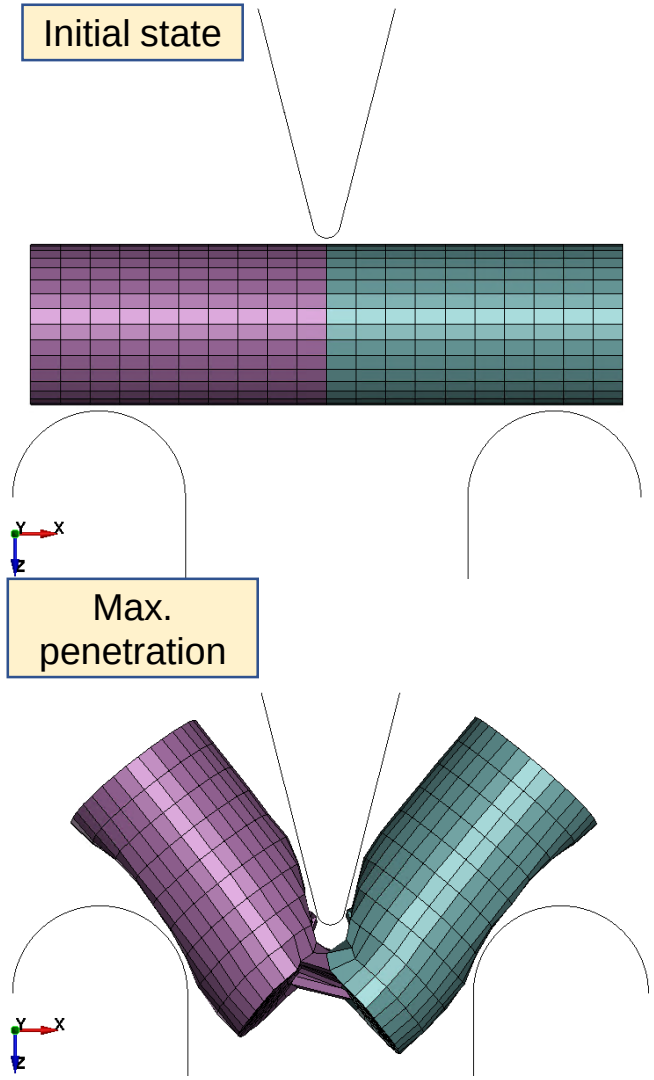
— test curves

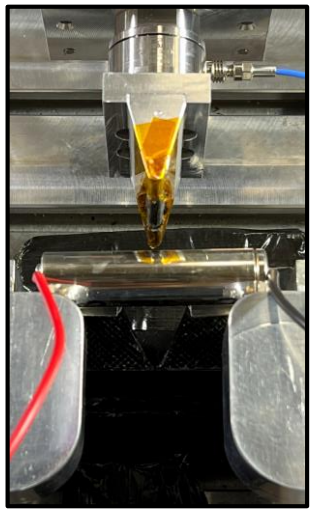
— validation results of simulation

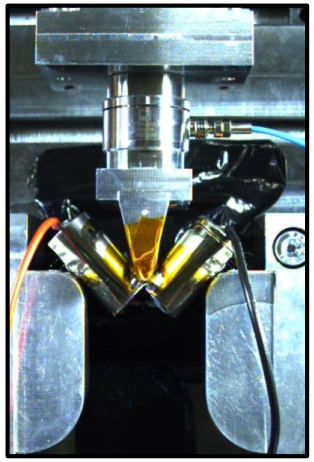
- Failure behaviour at higher intrusion also well predicted

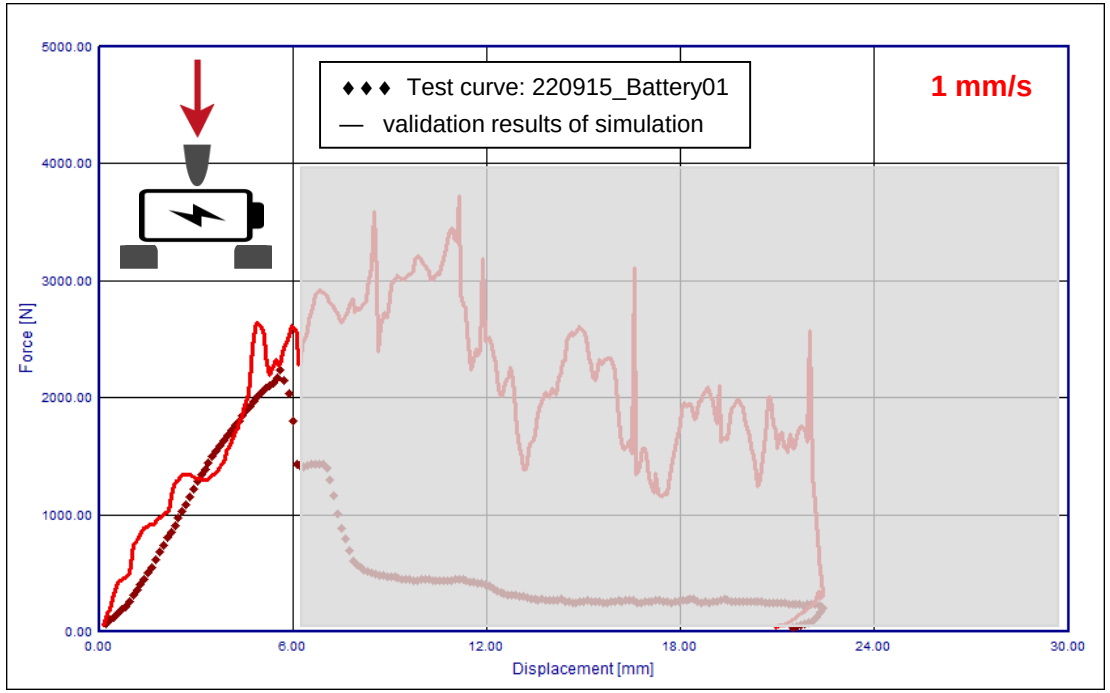
Analysis results - 18650 battery cell

3-point bending, adjusted MAT024 & MAT063+MAT_ADD_EROSION





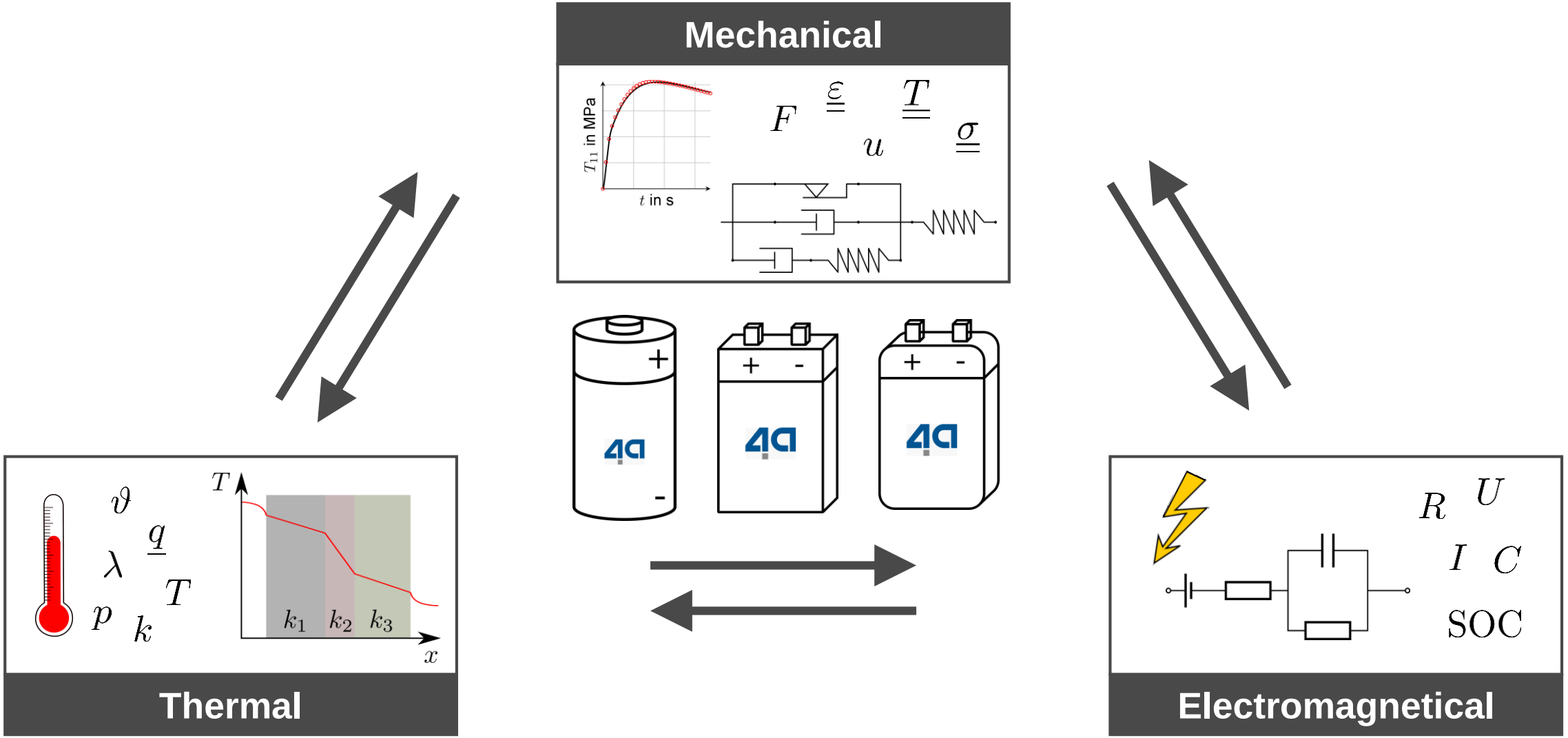




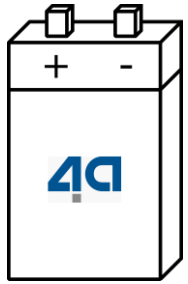
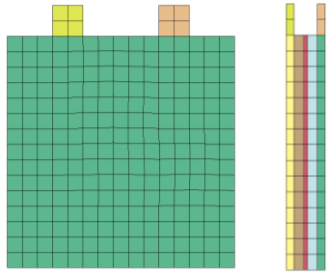
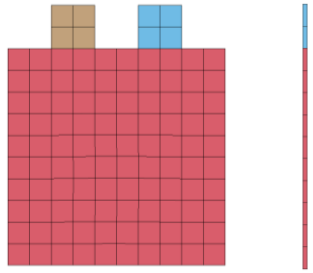
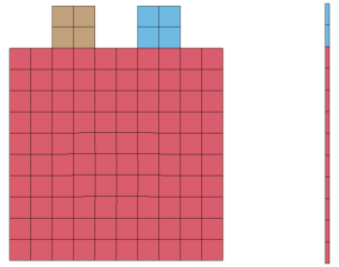
Same model used for 3 point bending load case:

- good representation of qualitative failure mode
- further optimization on post fracture behaviour required
- Work in progress…

Multiphysics of battery cells



Multiphysics modeling approaches in LS DYNA

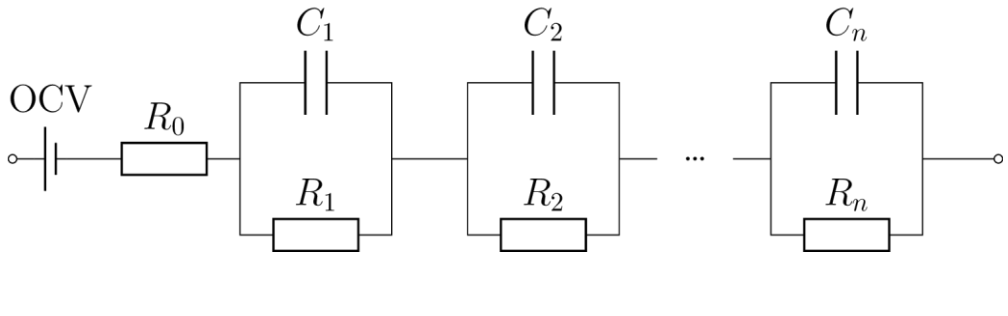
	Solid layer model	Tshell model	Batmac model
			
Keyword	*EM_RANDLES_SOLID	*EM_RANDLES_TSHELL	*EM_RANDLES_BATMAC
Advantages	▪ Analysis of the different layers is possible	• Benefical modeling of thin cells • Reduced computational effort	▪ Modeling with respect to mechanical and thermal problem ▪ Least computational effort
Disadvantages	• Computational effort • Characterization of the materials of the layers required	• Homogenized mechanical material model • Behavior of the layers can not be analyzed in detail	• Homogenized material models • Behavior of the layers can not be analyzed

Electrical modelling and characterization

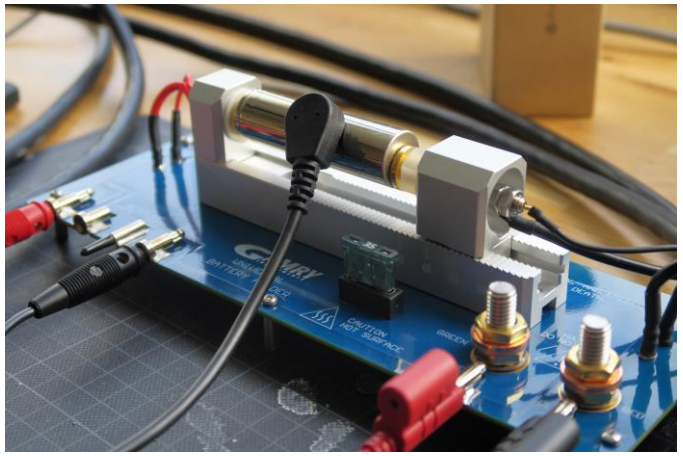
Panasonic
NCR18650B

3250 mAh

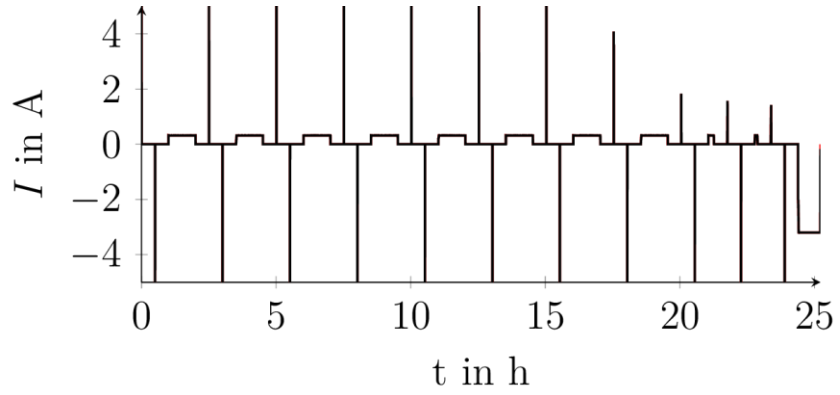
18650 cell

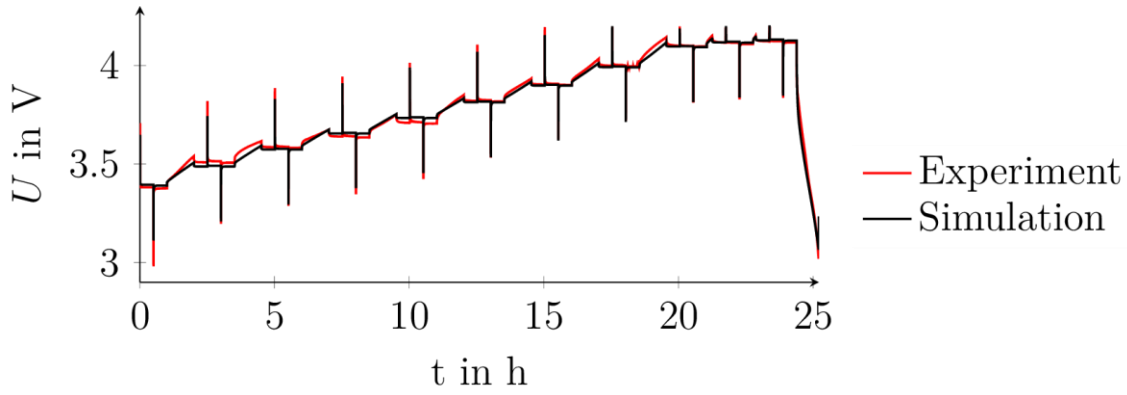


Randle's circuit model (nth order)



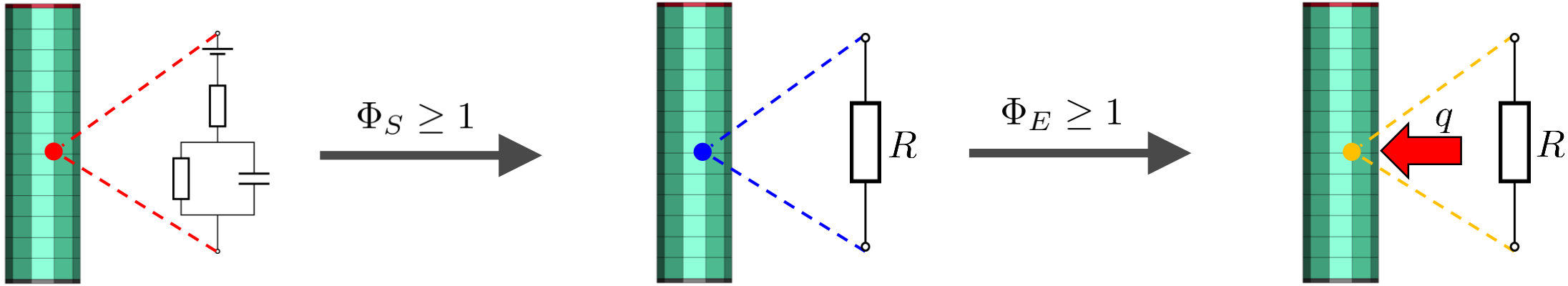
- Identification of the parameter based on the 4a HPPC test





Abuse simulation of a single cell

- Modeling of the electrical behavior, the internal short circuit and the exothermal reaction



Initiation criterion:

$$\Phi_S\left(T, \mathrm{SOC}, \underline{\underline{\varepsilon}}\right) \geq 1$$

Short resistance:

$$R = \mathrm{const.}$$

Internal short circuit

Initiation criterion:

$$\Phi_E\left(T\right) \geq 1$$

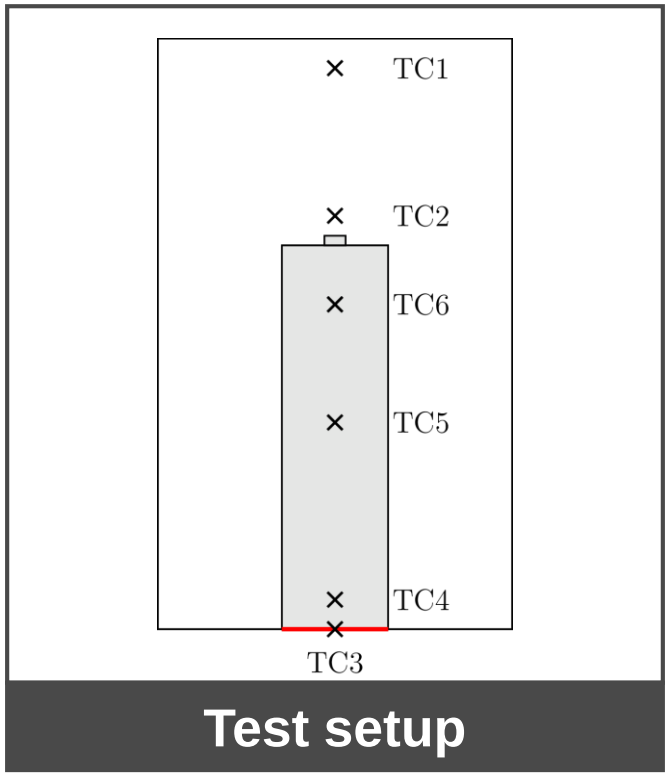
Additional heat source:

$$q\left(T\right)$$

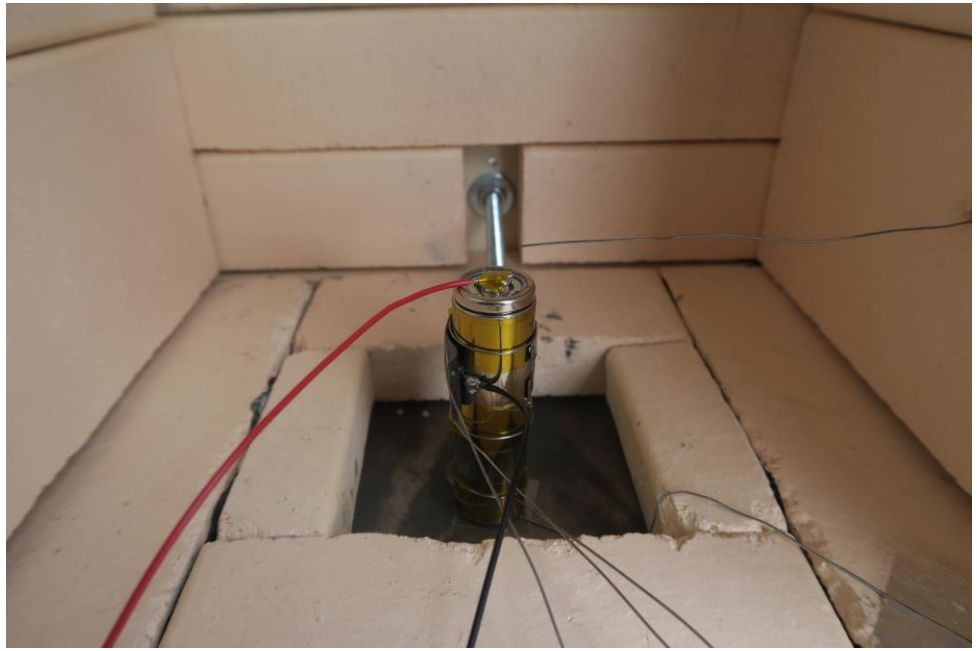
Exothermal reaction

Overheat test of a battery cell

- Overheating of a fully charged 18650 battery cell (Panasonic NCR18650B) at the bottom
- Measurement of the temperature at the cell as well as in the chamber with 6 thermocouples
- Measurement of the voltage

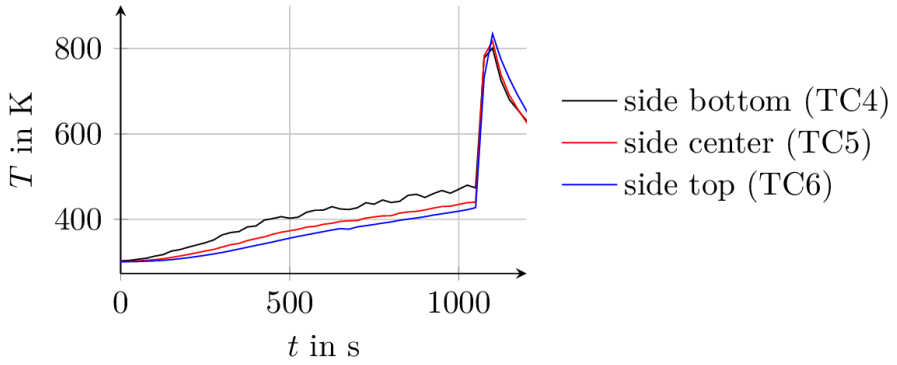


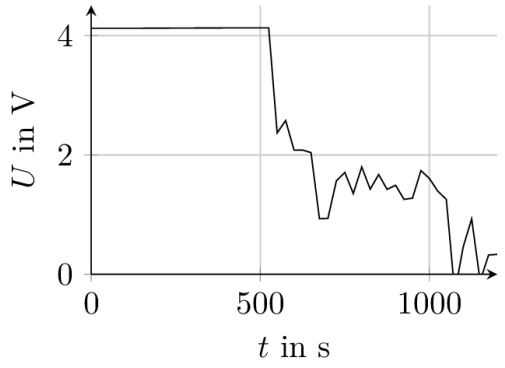
Test setup



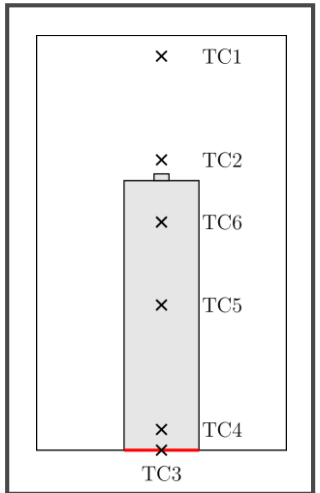
Overheat test of a battery cell

Overheat test of a battery cell

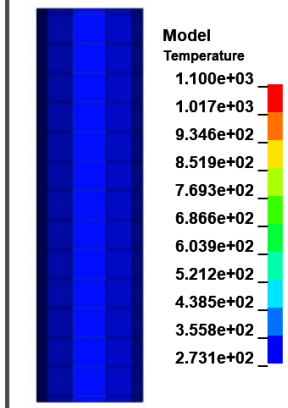




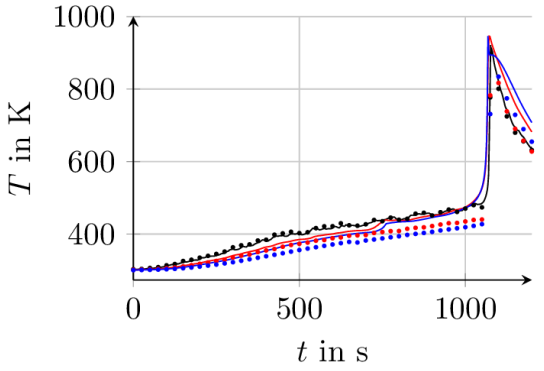
Test results

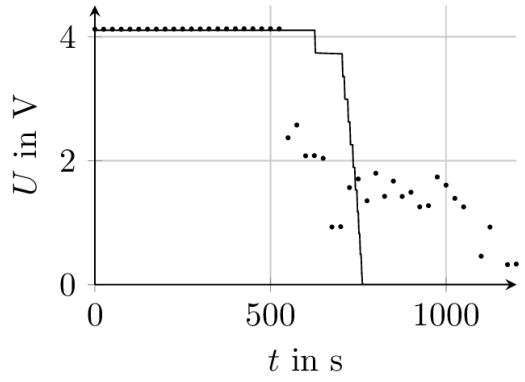


Test setup



FE model

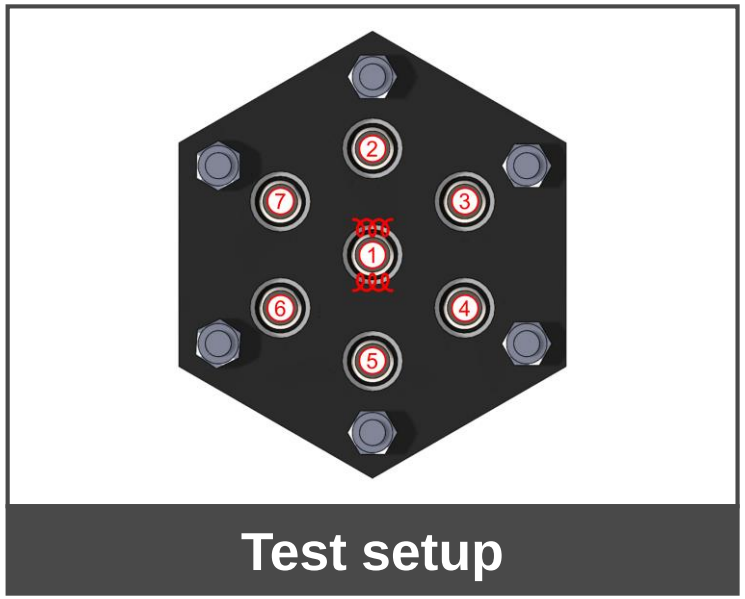




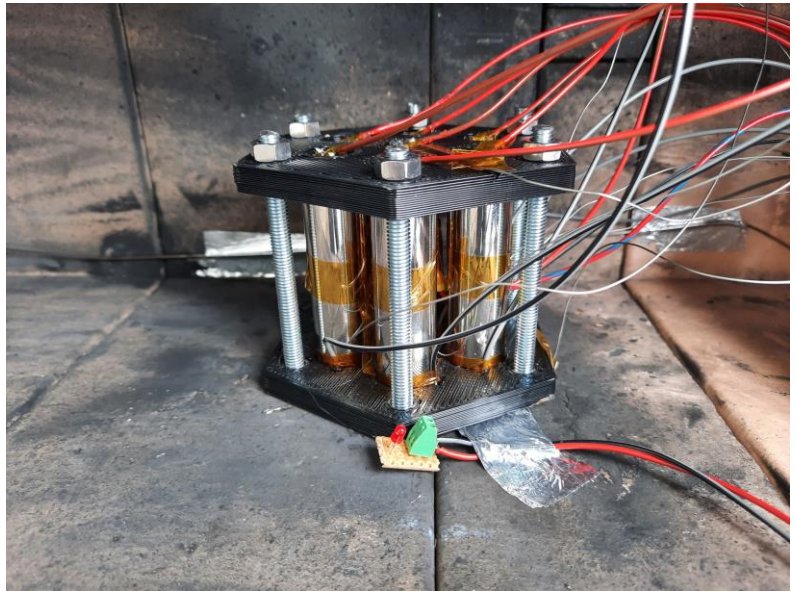
Simulation results

Multi-cell mockup – experimental investigation

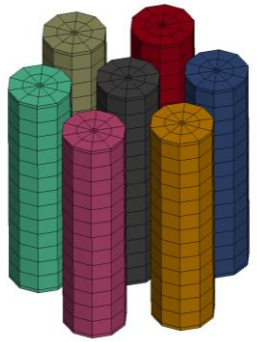
- Thermal runaway of the center cell induced by heating with a heating wire
- Temperature and voltage measurement of each cell
- Video recording with high-speed camera

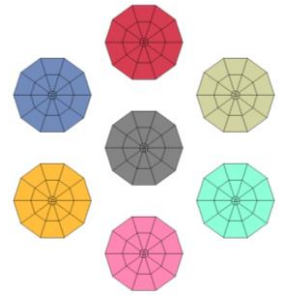


Test setup

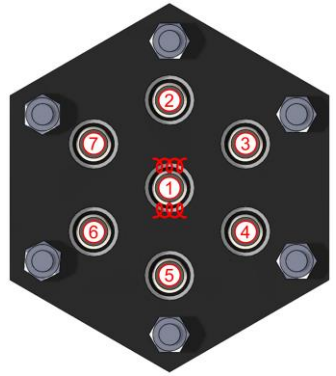


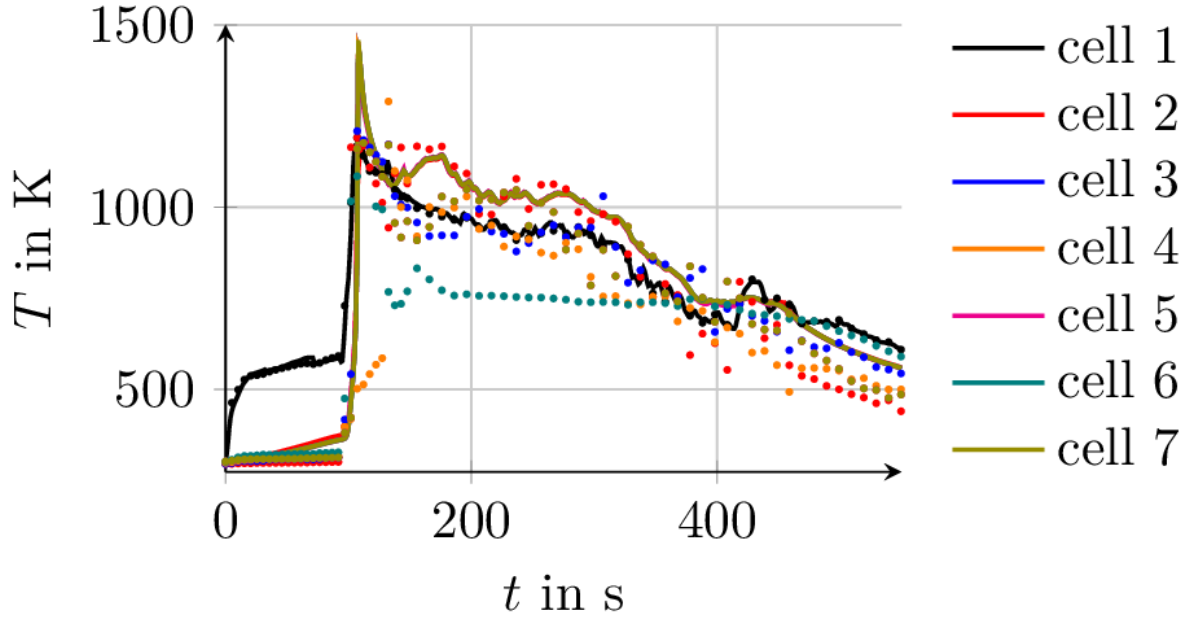
Multi-cell mockup – simulation results

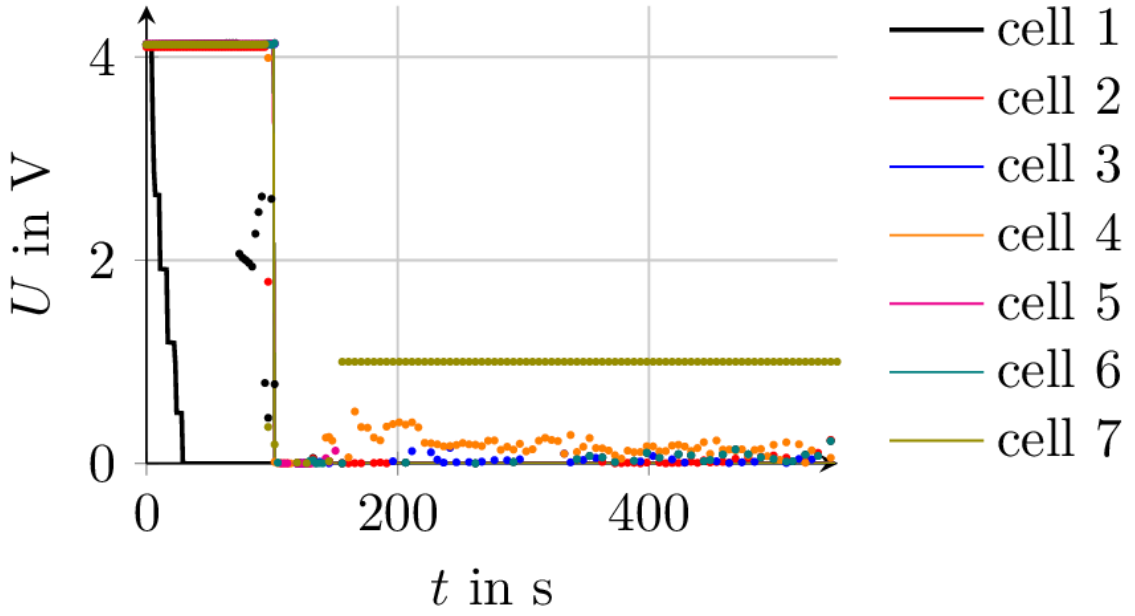




FE model





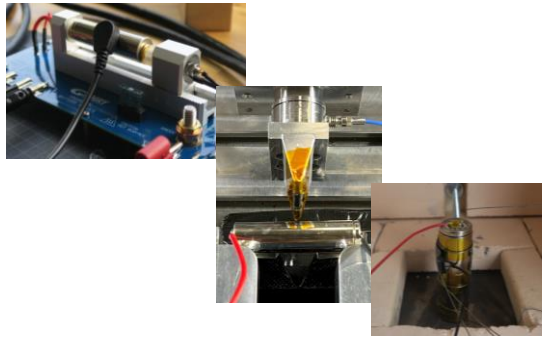


· experiment —— simulation

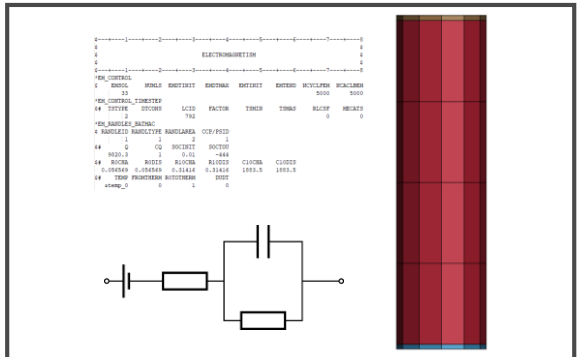
Conclusion and outlook

Conclusion

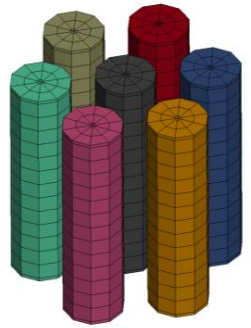
Battery Cell



Testing



Model – single cell



Application

Outlook

- Development of test setups for further characterizations of battery cells especially with regards to thermal and mechanical abuse
- Automatic identification of the parameters required for the resulting FE model
- Optimization of battery packs addressing the thermal propagation and crash behavior

Improve your developments with our expertise in testing and simulation!

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